Compact Integration of Aerodynamic Control and Thrust Vector Control

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GENERAL DYNAMICS
Ordnance and Tactical Systems

Introduction

- **Mission flexibility is critical to meeting cost and logistics objectives for new weapon systems**
- **Three-axis (pitch, yaw, roll) aero control systems inadequate at low Mach and high alpha conditions**
- **Current 3-axis TVC systems (multiple nozzles and jet vanes) are:**
  - Large
  - Costly
  - Inefficient
- **Technology is now mature to integrate aero control with 3-axis TVC for 5 – 13 inch diameter tactical missiles**

Current State Of The Art

System	Attributes
Standard Missile - Mk72	
• Moving Nozzles	**No drag / Thrust loss**
• Separate TVC Actuators	High cost
NETFIRES	
• Jet Tabs	Drag losses up to 7%
• Separate Actuators for each tab	High cost
AIM-9X	
• Jet Vanes	2-3 inches added length
• Vanes slaved off fin servos	**Low cost**

Coupled IATVC System Combines the best Attributes of prior systems

Historical Perspective of IATVC

Yoke Plate TVC Developed
Patent #4,893,253

6-Axis IATVC Static Test

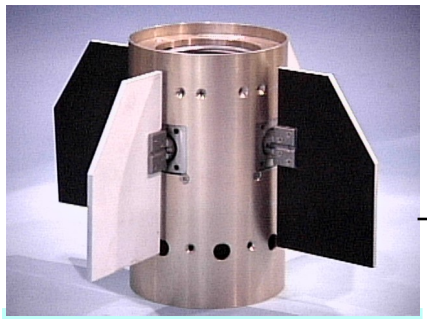
DifferentialYoke Plate Mechanism Developed

Patent #5,566,087

Apply to Multiple Nozzle Motor (Adds Roll Control)

985 **1990** **1995** **2000** **2005**

6-Axis IATVC Produced



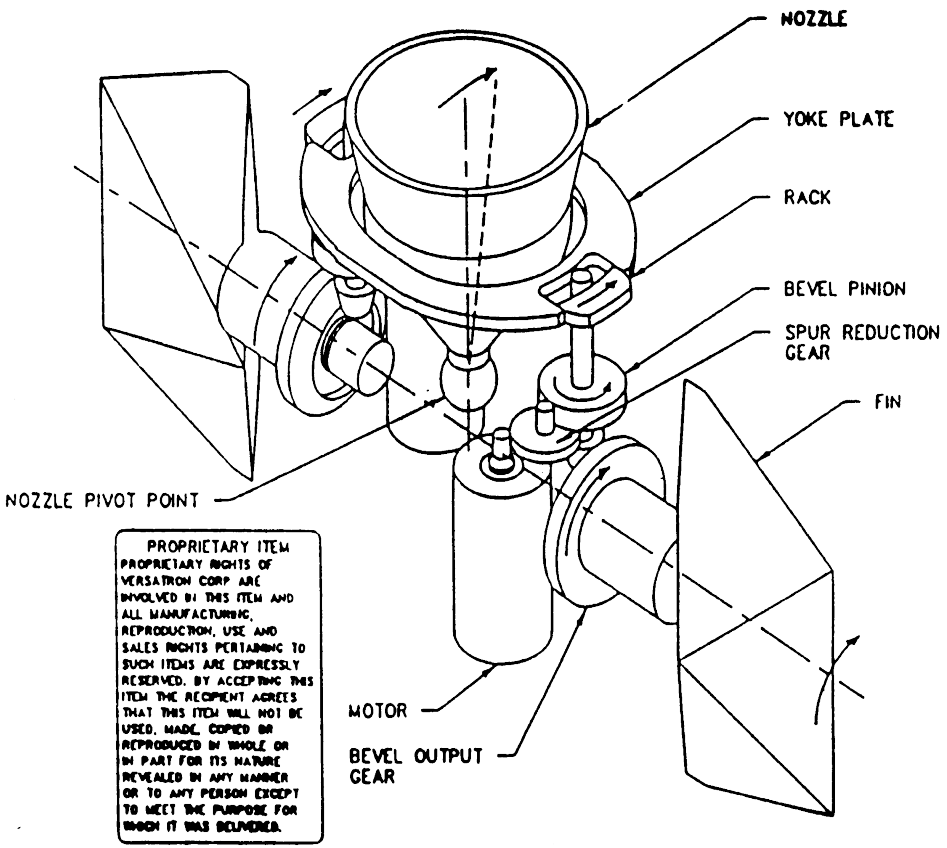
Phase II SBIR (Detail Design/Fab/Test)

Static Test on 3 Pulse Motor

Single Nozzle IATVC

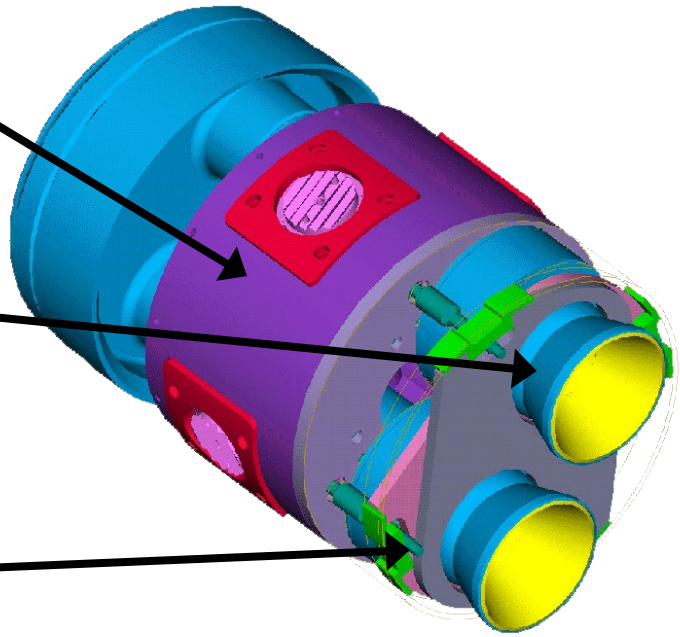
- **Pitch/Yaw TVC only**
- **Roll component of fin motion de-coupled**
- **Nozzle motion =**

  Algebraic sum of opposite fin motion in pitch/yaw


NOZZLE
YOKE PLATE
RACK
BEVEL PINION
SPUR REDUCTION GEAR
FIN
NOZZLE PIVOT POINT
MOTOR
BEVEL OUTPUT GEAR
PROPRIETARY ITEM
PROPRIETARY RIGHTS OF VERSATRON CORP ARE INVOLVED IN THIS ITEM AND ALL MANUFACTURING, REPRODUCTION, USE AND SALES RIGHTS PERTAINING TO SUCH ITEMS ARE EXPRESSLY RESERVED. BY ACCEPTING THIS ITEM THE RECIPIENT AGREES THAT THIS ITEM WILL NOT BE USED, MADE, COPIED OR REPRODUCED IN WHOLE OR IN PART FOR ITS NATURE REVEALED IN ANY MANNER OR TO ANY PERSON EXCEPT TO MEET THE PURPOSE FOR WHICH IT WAS DELIVERED.

Three Key Enabling Technologies

- **Compact brushless DC electromechanical actuators**
- **Compact moving nozzles**
- **Yoke plate linkage to couple the motion of 2 nozzles and fins**

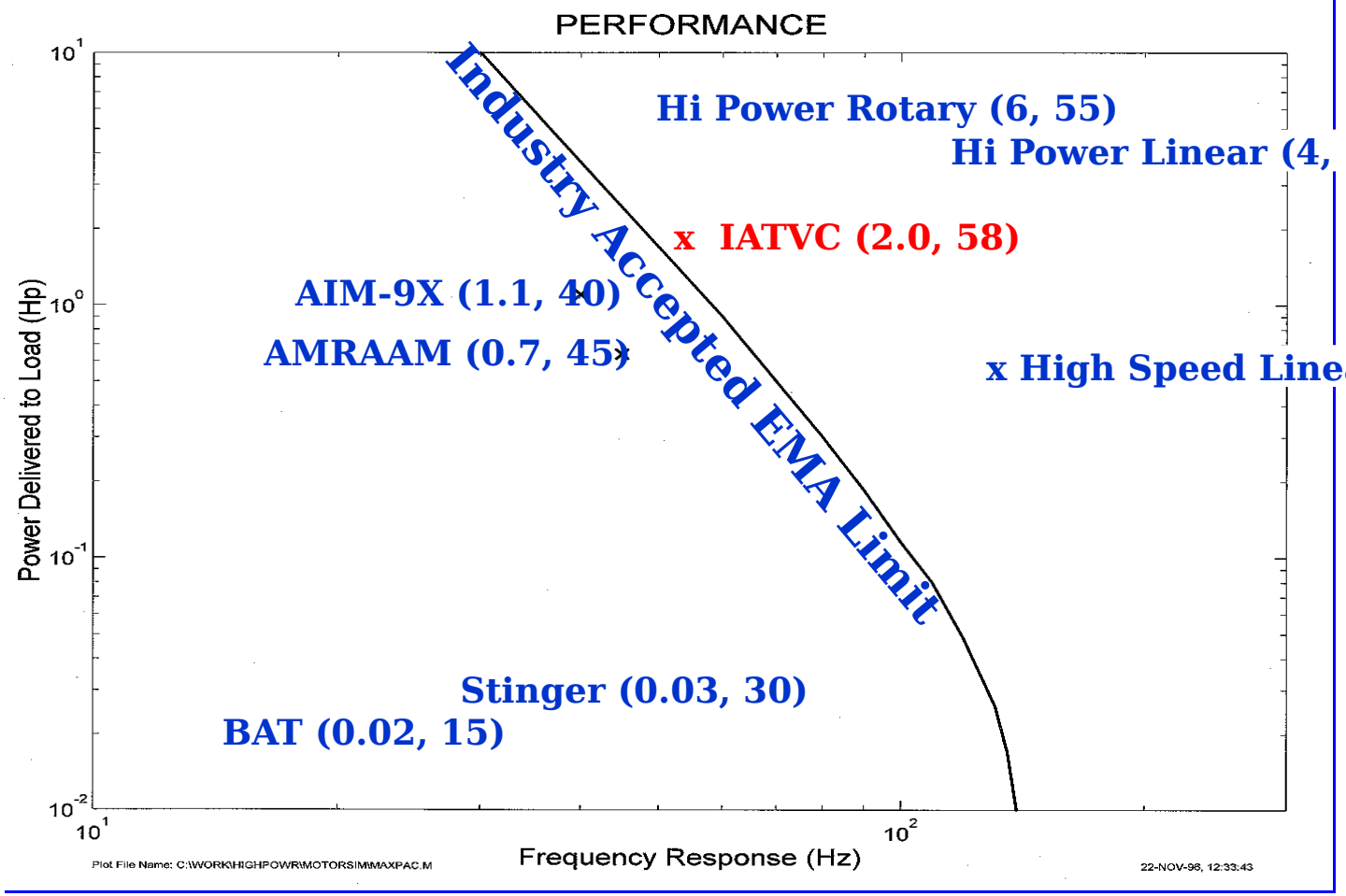


Compact Electromechanical Actuator

- **Brushless DC Servo motor**
  - GD-OTS Lo-J motor
  - Very high torque to inertia ratio
  - Demonstrated 160 Hz bandwidth
  - 6.1 HP in the size of “D” cell battery
- **Compact Gearbox Assembly**
  - High Ratio (374:1) Spur Gear Reductio
- **Custom Packaged COTS Electroni**
  - Low Cost Commercial IC’s
  - Very Low Resistance FETs

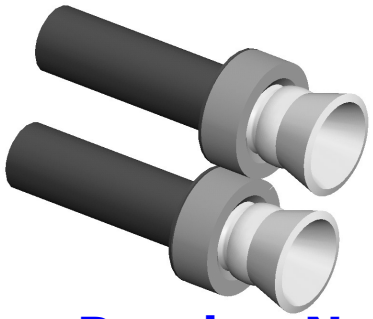
Single Axis Fin Gearbox with TVC Power Take-off

Power Rate Density – GDOTS Enabling Technology

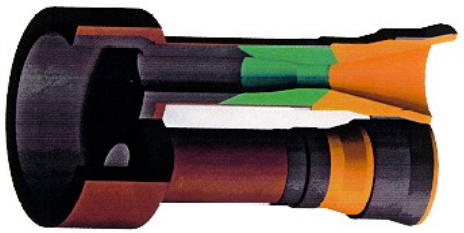


Nozzle Considerations

- **Flex Bearing**
  - Low actuator loads
  - Moderate – High cost
  - Largest volume
- **Trapped ball**
  - High friction torque
  - Low cost
  - Compact
- **Flexible Exit Cone (INOVEC)**
  - Moderate Actuator loads
  - Lowest cost
  - Smallest volume
  - Limited maturity



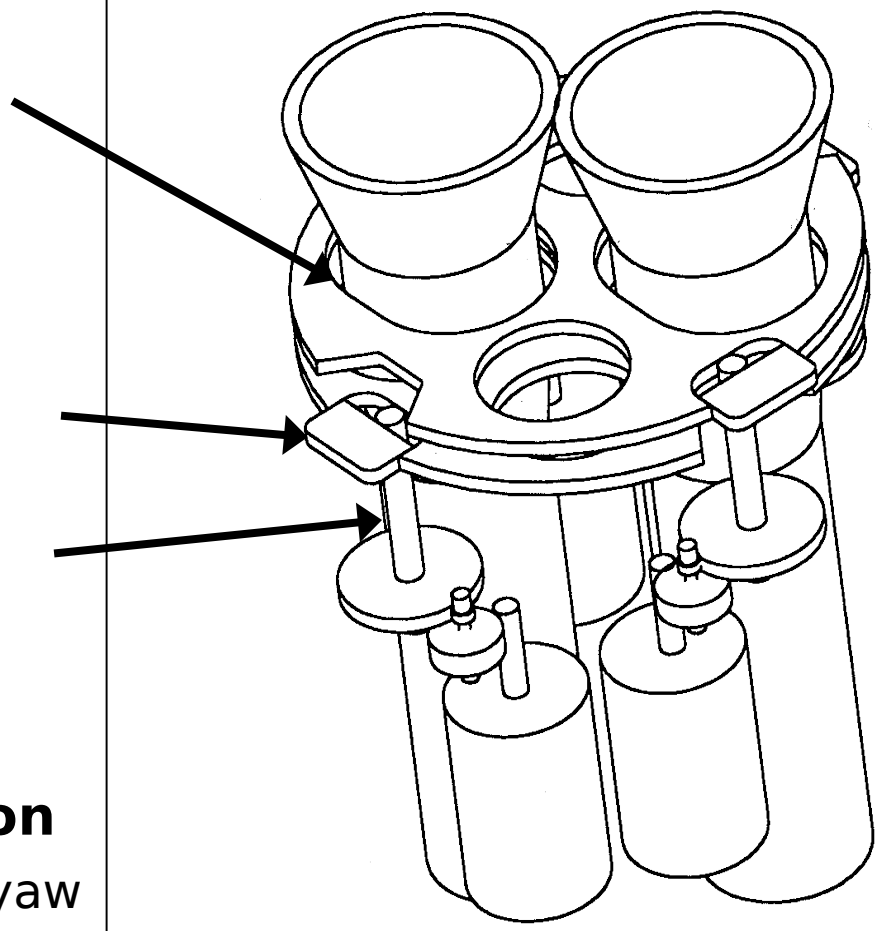
Flex Bearing Nozzles



Flexible Exit Cone

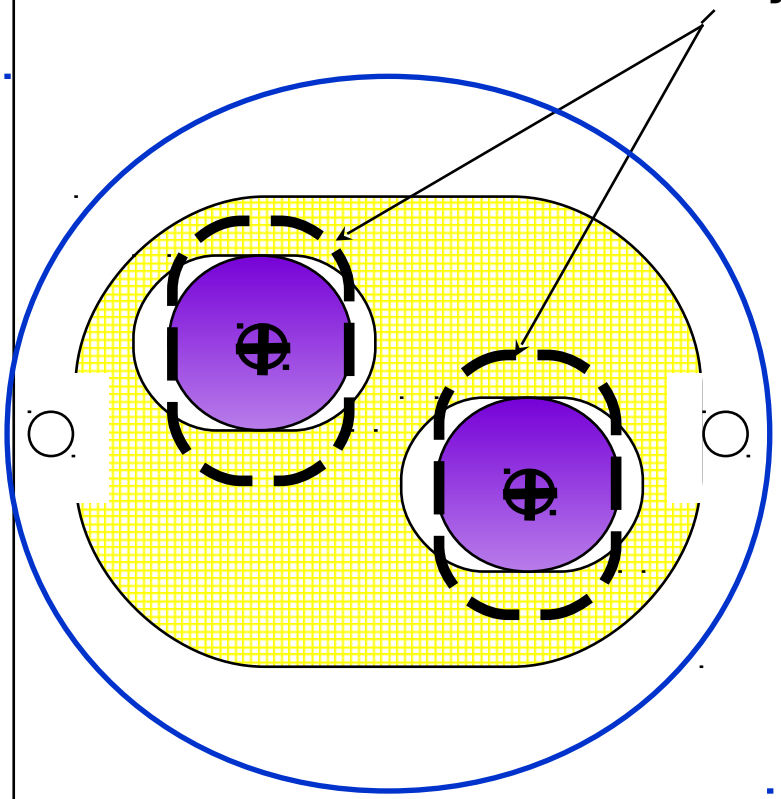
Dual Nozzle Yoke Plate Mechanism

- **Two "yoke" plates**
  - Slot limits motion in 1 plane
  - 1 plate for each axis
  - Both plates impart roll motion
- **Rack Gears drive each plate in 1 plane**
- **Racks coupled to fin servos**
- **Resulting nozzle motion**
  - Algebraic sum of pitch, yaw and roll motion of fins

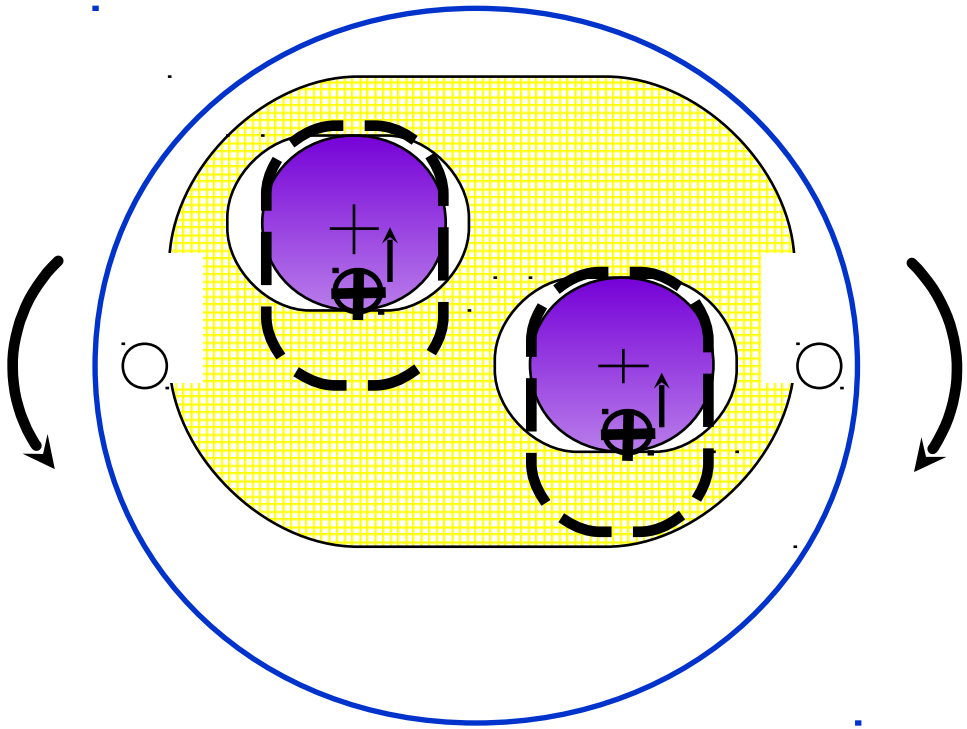


Pitch and Yaw Plate / Nozzle Motion

Nozzles can only move along one axis since they are constrained by the slots in the other yoke plate (not show



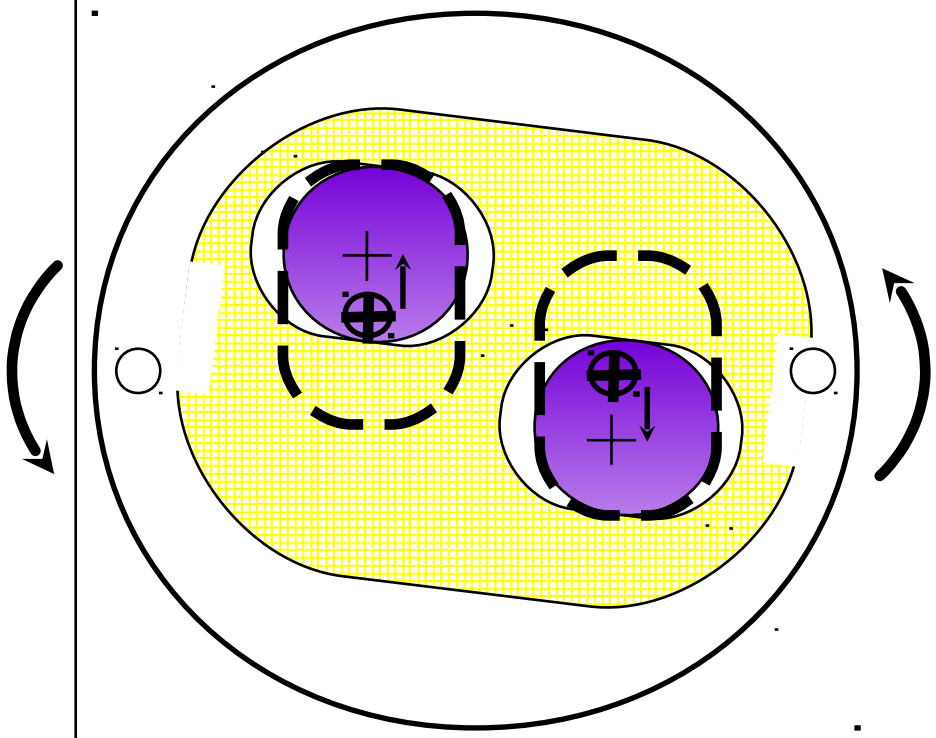
Nominal Position



Pure Pitch/Yaw Moti

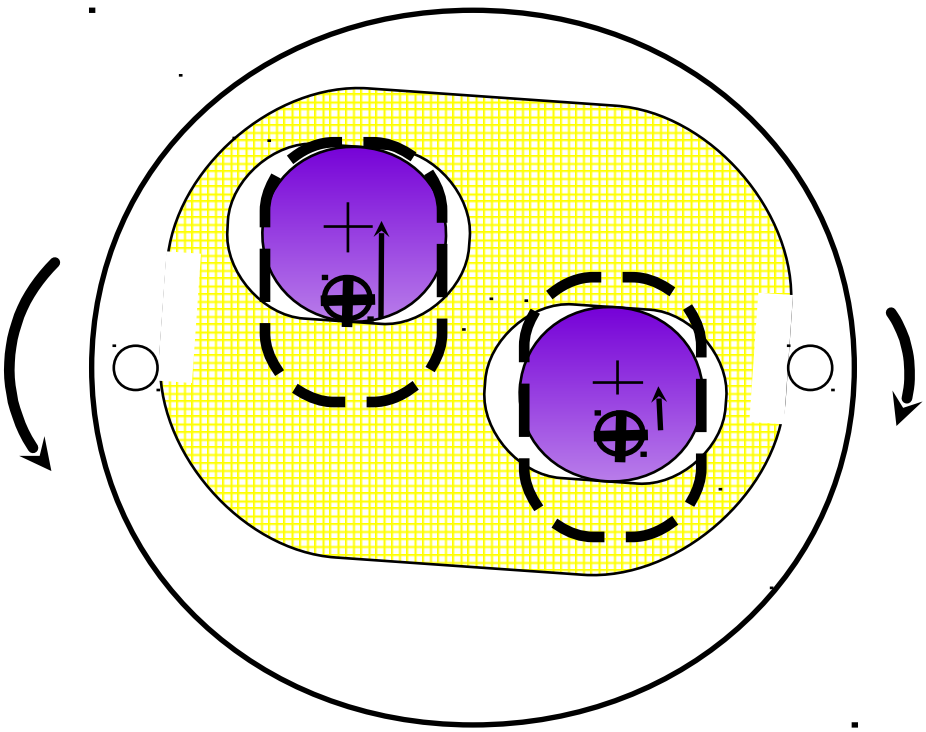
Both nozzles move same amoun in the same direction

Roll Plate / Nozzle Motion



Pure Roll Motion

Both nozzles move same amount but in opposite directions



Pitch and Roll Motion

System Performance

Parameter	Units	Requirement	Actual
Fin No load Speed	Deg/sec	>600	1150
Fin Stall Torque	In-lbs	>800	1700
Fin Travel	Deg	±30	±50
Fin Axis Bandwidth	Hz	>45	58
TVC Slew	Deg/sec	200	380
TVC Angle	Deg	±10	±10
Position Accuracy	Deg	±0.2	±0.15
TVC Side Force	Lb	500	500
TVC Roll Moment	In-lb	720	720

Static Rocket Motor Testing

- **7 inch motor**
  - Modified AMRAAM +5
- **Demonstrated 3 axis TVC**
- **Aerofin Operation for 60 sec**
  - After motor burn-out
  - Demonstrate nozzle integrity
  - Servo performance after nozzle cooling

Applications / Benefits

Product/Program	Key Benefit
• CLAWS requirements	Reduce launcher slew
• AIM-9X	Reduce losses due to vane drag
	Reduce missile length by 2-3 inches
• NETFIRES	Eliminate separate tab servos
• JCM	Increased maneuverability

Conclusions

- **GD-OTS has demonstrated all key technologies for a 3-axis IATVC system that is:**
  - Low cost
  - Lightweight
  - Compact
  - High performance
- **System provides 3-axis control for high-agility air-to-air air-to-ground or ground-to-ground missiles in all flight regimes**
- **Integrated Dual Moveable Nozzle TVC is:**
  - More compact than existing systems
  - Less parasitic drag loss than jet vanes or tabs
  - Low cost by leveraging existing Aero-fin servos